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CYGNUS PFL SWITCH JITTER *

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Abstract

The Cygnus Dual Beam Radiographic Facility consists of two identical radiographic sources: Cygnus 1 and Cygnus 2. Each source has the following X-ray output: 1-mm diameter spot size, 4 rads at 1 m, 50-ns full-width-half-maximum. The diode pulse has the following electrical specifications: 2.25 MV, 60 kA, 60 ns. This Radiographic Facility is located in an underground tunnel test area at the Nevada Test Site (NTS). The sources were developed to produce high-resolution images on subcritical tests performed at NTS. Subcritical tests are single-shot, high-value events. For this application, it is desirable to maintain a high level of reproducibility in source output. The major components of the Cygnus machines are Marx generator, water-filled pulse forming line (PFL), water-filled coaxial transmission line, three-cell inductive voltage adder, and rod-pinch diode. A primary source of fluctuation in Cygnus shot-to-shot performance may be jitter in breakdown of the main PFL switch, which is a "self-break" switch. The PFL switch breakdown time determines the peak PFL charging voltage, which ultimately affects the source X-ray spectrum and dose. Therefore, PFL switch jitter may contribute to shot-to-shot variation in these parameters, which are crucial to radiographic quality. In this paper we will present PFL switch jitter analysis for both Cygnus machines and present the correlation with dose. For this analysis, the PFL switch on each machine was maintained at a single gap setting, which has been used for the majority of shots at NTS. In addition the PFL switch performance for one larger switch gap setting will be examined.

I. CYGNUS SYSTEM

A. General Description

Cygnus is a two-axis radiographic X-ray system designed to drive rod-pinch diode loads [1], [2]. The system consists of two virtually identical accelerators known as Cygnus 1 and Cygnus 2. The space constraint at the underground NTS tunnel facility requires an in-line layout for the two Marx generators as shown in Figure 1. The only two noticeable differences between the two machines are the length of water transmission line that connects the PFL to the inductive voltage adder (IVA), and the angling of the diode axes which are mirror images of each other.

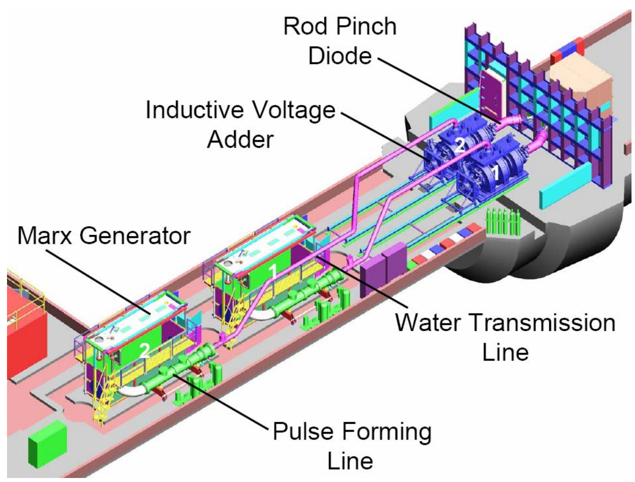

Figure 1. Cygnus underground facility configuration.

B. Pulse Forming Line Description

The PFL System is composed of three water-insulated coaxial lines, each terminated with a self-break switch.

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14. ABSTRACT
The Cygnus Dual Beam Radiographic Facility consists of two identical radiographic sources: Cygnus 1 and Cygnus 2. Each source has the following X-ray output: 1-mm diameter spot size, 4 rads at 1 m, 50-ns full-widthhalf- maximum. The diode pulse has the following electrical specifications: 2.25 MV, 60 kA, 60 ns. This Radiographic Facility is located in an underground tunnel test area at the Nevada Test Site (NTS). The sources were developed to produce high-resolution images on subcritical tests performed at NTS. Subcritical tests are single-shot, high-value events. For this application, it is desirable to maintain a high level of reproducibility in source output. The major components of the Cygnus machines are Marx generator, water-filled pulse forming line (PFL), water-filled coaxial transmission line, threecell inductive voltage adder, and rod-pinch diode. A primary source of fluctuation in Cygnus shot-to-shot performance may be jitter in breakdown of the main PFL switch, which is a self-break switch. The PFL switch breakdown time determines the peak PFL charging voltage, which ultimately affects the source X-ray spectrum and dose. Therefore, PFL switch jitter may contribute to shot-to-shot variation in these parameters, which are crucial to radiographic quality. In this paper we will present PFL switch jitter analysis for both Cygnus machines and present the correlation with dose. For this analysis, the PFL switch on each machine was maintained at a single gap setting, which has been used for the majority of shots at NTS. In addition the PFL switch performance for one larger switch gap setting will be examined.

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Table 1. PFL System components.

Line Component			Switch	
PFL	4.8/7.3 Ω	35 ns	PFL	Water
1st Output	7.8 Ω	35 ns	Peaking	Water
2nd Output	7.8 Ω	40 ns	Pre-Pulse	Oil

The components and corresponding switches, with specifications, are given in Table 1. Note "PFL" may be used to denote either the singular PFL Line Component, or the entire PFL System. The PFL Line has a stepped impedance that compensates for a drooping load impedance, which is typical of a rod-pinch diode. The Pre-Pulse Switch is oil-filled unlike the other two switches.

The PFL has four capacitive voltage monitors. Two monitors (Vpfl1, Vpfl2) are located in the PFL Line. One monitor (Vpfl3) is in the 1st Output Line, and one monitor (Vpfl4) is located in the 2nd Output Line.

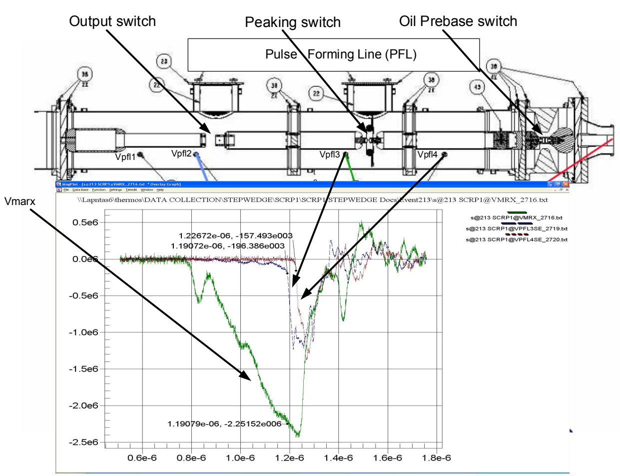

Figure 2. Cut away view of the Cygnus PFL.

The PFL System components and voltage monitors are shown in a cut away view in Figure 2. A photograph of the PFL is given in Figure 3.

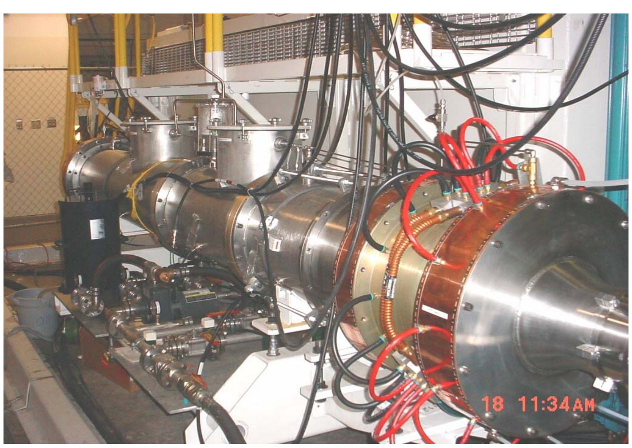

Figure 3. Pulse forming line (PFL).

II. PFL SWITCH JITTER

A. *Relevance*

The purpose of the Cygnus sources is time-resolved radiography for dynamic material science experiments. Information from the radiographs is incorporated into computer models used to depict material properties. Since Cygnus is a vital diagnostic for subcritical tests, performance improvements that lead to higher quality radiographs have become the focus of users. PFL Switch breakdown time determines PFL charging voltage, end-point energy, electron spectrum, and ultimately X-ray spectrum. Also dose is affected since it results from a combination of electron spectrum and current. Therefore, jitter in the PFL Switch contributes to shot-to-shot fluctuation in the X-ray spectrum and dose. A reduction in PFL Switch jitter may improve source reproducibility, which is extremely important in precise interpretation of the subcritical test radiographs. The diagnostic immediately downstream of the PFL switch (Vpfl3) was used to measure PFL switch jitter. It has a highly consistent shape that can be precisely linked to switch breakdown time. Figure 4 is an overlay of four typical Vpfl3 traces which demonstrates jitter.

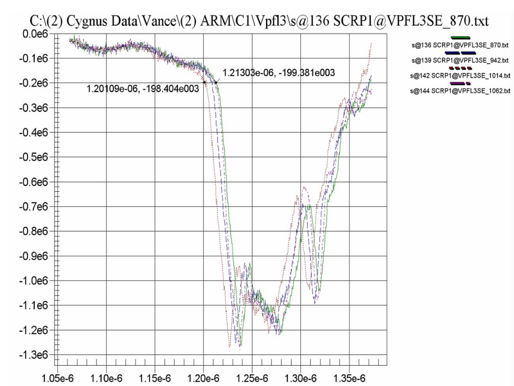

Figure 4. Four Vpfl3 traces showing main PFL switch jitter. From the Cygnus 1 Armando series.

B. *Measurement*

PFL switch jitter for both Cygnus X-ray sources is presented in Table 2. The results are segregated according to the Cygnus project series. The first three rows correspond to the nominal 3.4–3.5 in. switch gap. Moreover, analysis was done on a small sub-set of Cygnus 2 shots where the switch gap is 3.75 in. This test set is defined as Thermos* and comprises the fourth row.

Table 2. PFL switch jitter.

Project Series	Gap (in)	Cygnus 1 (ns)	Cygnus 2 (ns)
Armando	3.4-3.5	13	10
Step Wedge	3.4-3.5	9	11
Thermos	3.4-3.5	14	14
Thermos*	3.75	--	13

C. Dose correlation

In this work X-ray dose is the parameter chosen for comparison with PFL switch time. Thermoluminescent dosimeters are used to measure the individual machine dose on every shot. In the following graphs, PFL switch time and dose versus shot are plotted. The measurements are segregated according to project series as shown in Table 3.

Table 3. PFL / Dose figures.

Project Series	**Cygnus 1**	**Cygnus 2**
Armando	Figure 5	Figure 6
Step Wedge	Figure 7	Figure 8
Thermos	Figure 9	Figure 10
Thermos*	---	Figure 11

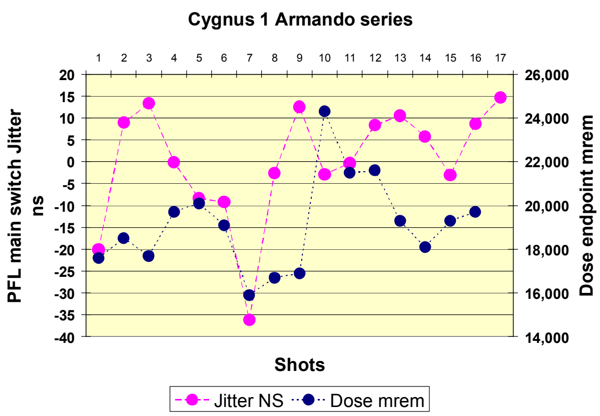

Figure 5. Cygnus 1 – Armando series.

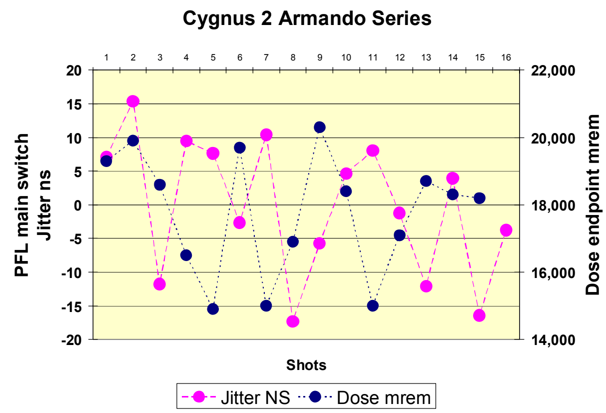

Figure 6. Cygnus 2 – Armando series

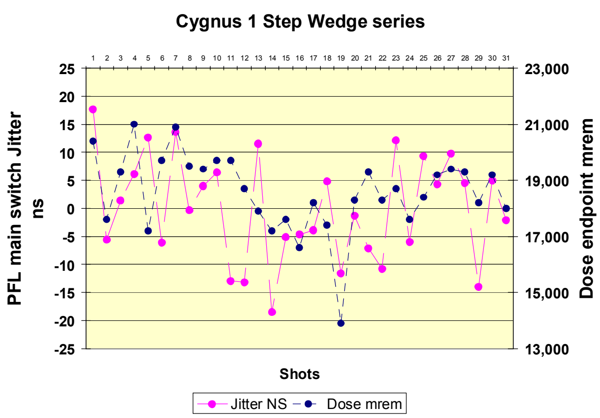

Figure 7. Cygnus 1 – Step Wedge series.

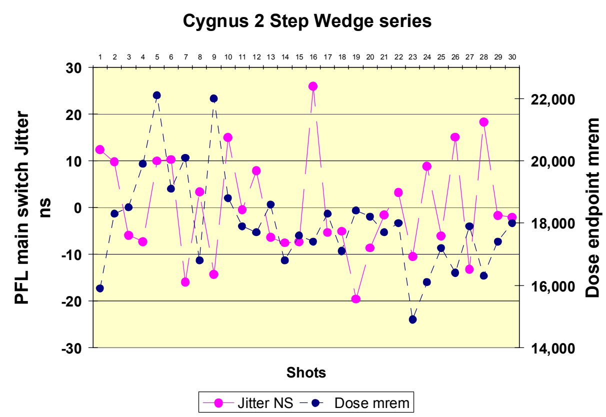

Figure 8. Cygnus 2 – Step Wedge series.

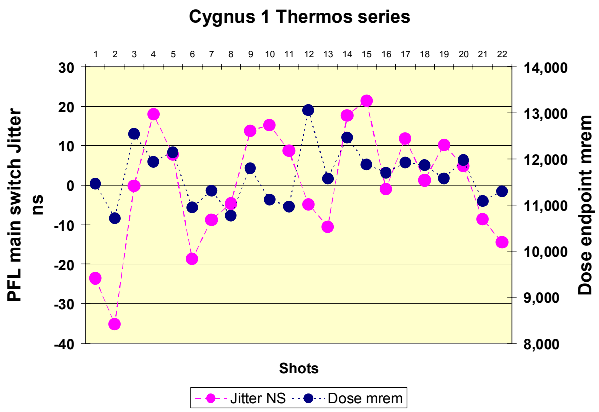

Figure 9. Cygnus 1 – Thermos series.

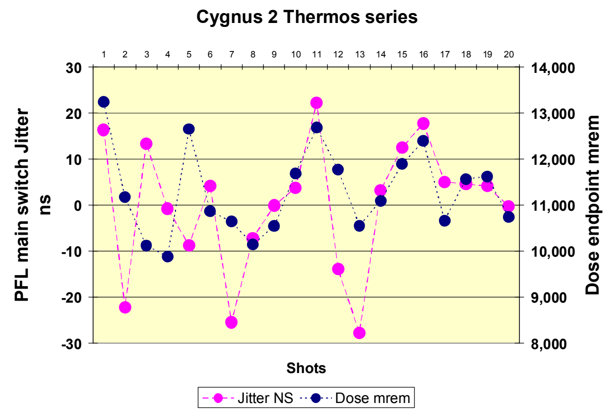

Figure 10. Cygnus 2 – Thermos series.

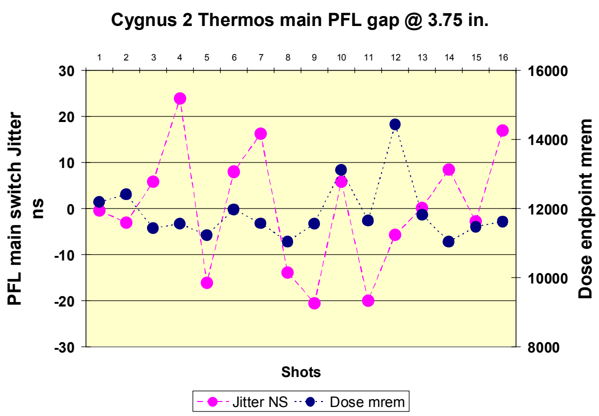

Figure 11. Cygnus 2 – Thermos* series.

III. SUMMARY

Refer to Table 2 for the following discussion. First, consider the comparison of PFL Switch jitter between the different project series (Armando, Step Wedge, and Thermos). Within a few ns, the jitter was comparable on Cygnus 1 as well as on Cygnus 2. Next, compare the jitter results between the two machines (Cygnus 1 and Cygnus 2). Again, within a few ns, the jitter was comparable for all three project series. The data used in this analysis, from different project series and machines, encompasses many variables that are typically encountered over an extended period of operation (e.g., electrode surface quality, insulating water quality, hardware components).
The results indicate PFL Switch jitter is not a strong function of any of these variables.

The jitter for the 3.75 in. PFL gap tests is comparable with the jitter for standard shots with 3.4–3.5 in. gap. However, the average dose was ~5% higher for the shots using the 3.75 in. PFL gap as compared with average dose for standard shots. The larger gap setting is attractive from the standpoint of increased endpoint energy and dose. However, the corresponding increased PFL charging time
may have contributed to tracking of the PFL oil–water barrier which occurred during the Thermos series. It was decided the increased dose advantage was not worth the increased risk of barrier failure. Therefore, the PFL gap was returned to the 3.4–3.5 in. setting.

Clean PFL switch electrodes were installed at the beginning of Armando and Thermos. Although many shots were executed in both series, there was no clear jitter increase due to switch deterioration. However, since there was a correlation noted on the Radiographic Integrated Test Stand (RITS) at Sandia National Laboratories [3], clean PFL switch electrodes will be installed at the beginning of the next series of shots. Further analysis of switch jitter verses deterioration will be performed.

Review of Figures 5–11 shows no strong correlation between PFL switch time and dose. Note, from the X-ray source standpoint, dose is a function of both electron spectrum and current, and X-ray spectrum is a function of electron spectrum only. Therefore, the X-ray spectrum may be a more sensitive indicator of the influence of jitter on source quality than dose. Future efforts will involve comparison of the X-ray spectrum with PFL Switch time. If a marked correlation is discovered, experiments will be performed which focus on jitter reduction.

IV. REFERENCES

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